

## PATENT SPECIFICATION

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## COMPLETE SPECIFICATION

## Improvements in or relating to Sealing means between relatively Movable Parts

5 We, SOLAR AIRCRAFT COMPANY, a corporation of the State of California, United States of America, of 2200, Pacific Highway, San Diego, California, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

10 The present invention relates to apparatus comprising relatively movable parts and space sealing or filling means interposed between such parts.

15 The problem of preventing damage due to contact between relatively rotating and stationary parts operating with small clearances which are necessary to effect sealing has existed in the steam turbine field for many years. The advent of the jet engine and the gas turbine has aggravated this problem because of the markedly higher temperatures and rotating speeds involved. The slight unbalance existing in even the best of these power plants may be amplified dangerously during operation particularly if critical vibrations are encountered at the fundamental speed of the engine and may produce interference between close fitting labyrinth seals and shafts unless excessive tolerances are used. Because of the relatively high mass of both the shafts and the prior seals in such devices, immediate and severe localized heating results with attendant shaft distortion which increases the interference and the distortion. Such distortion can result in severe damage to or complete failure of the high speed equipment.

40 A similar problem which the present invention is uniquely effective in overcoming is presented by potential interference between the tips of rotating compressor or turbine blades and the surrounding casing. Contact between the tips of the rotating blades and the casing of the engine can be, and frequently is, produced when the blade grows abnormally in operation or when the casing is slightly dis-

torted for any reason such as uneven heating. It is frequently the case that high speed operation will cause a slight misalignment of one or more of the rotating blades which may then contact adjacent structure. Because of the high speed and high mass of the engine component involved, such contact may cause extensive damage.

50 In an effort to reduce the damage from such accidental contacts some blade tips have thin sections which sacrificially protect the main section of the blade. However, such sections cannot be incorporated in turbine or compressor blades without loss of aerodynamic efficiency.

60 In accordance with the present invention these and similar mechanical and sealing problems are solved by the provision of apparatus which include a yielding cellular construction adapted to occupy the space between the relatively moving parts and to yield when the space between the parts becomes less than the depth of the structure. The cellular construction may comprise a metallic open face honeycomb structure attached to a suitable support member. Such structures may readily be formed into a variety of useful configurations and may thus be readily adapted for use in widely varying environments.

75 Accordingly the primary purpose and object of the present invention is to provide means which is effective to minimize damage resulting from contact between relatively moving members.

80 It is another object of the invention to provide means which have unique flow control characteristics and which may be employed to restrict fluid flow as to effect a desired flow pattern between relatively movable members.

85 It is a more specific object of the invention to provide apparatus in which a cellular structure is mounted on a support to provide a plurality of cells open at one end and closed at the other end by the support member, the support member being adapted to be secured 90

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to one of two relatively moving members and the free edges of the cellular structure extending to a point closely adjacent the other of the relatively moving members.

5 Another important object is to provide a cellular structure which is attached to and becomes integral with one of two relatively movable massive structures, said cellular structure cooperating with said other relatively  
10 moving member to form a positive fluid flow seal or effective control therewith.

These and other objects will become apparent from the following detailed discussion, the appended claims and the annexed  
15 drawings in which:—

Figure 1 is a perspective view of one form of structural unit comprising a honeycomb structure and support member assembly constructed in accordance with the present invention;  
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Figure 2 is a similar view of a unit of modified form;

Figure 3 is a fragmentary sectional view of a further modification;

25 Figure 4 is a longitudinal section of a structural unit of the type shown in Figure 2 surrounding a rotating shaft;

Figure 5 is a transverse section taken along line 5—5 of Figure 4;

30 Figure 6 is a fragmentary longitudinal section of the unit of Figure 1 adapted for use as a radial seal;

Figure 7 is a fragmentary longitudinal section of a compressor blade in operating position with a honeycomb structure of the type shown in Figure 2 incorporated in a casing ring seal; and  
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Figure 8 is a section taken along line 8—8 of Figure 7.

40 Referring now more particularly to the drawings, Figure 1 illustrates a basic unit 10 which by appropriate variation in form may readily be adapted for a variety of uses. The unit 10 includes a cellular structure or  
45 assembly 12 which may be formed in a variety of ways before assembly with the support or backing member 14.

The cellular assembly 12 is preferably metallic and various metals may be used depending upon the requirements of a particular installation. Aluminum and stainless steels have been used with success. The thickness of the metal forming the assembly 12 may vary widely and thicknesses of from .001" to .012" have been successfully used. However the thickness is not critical and may be determined empirically with reference to the service requirements of the installation in which the unit is installed, it being expected that as the size of the units and the mass of the members involved increases greater thicknesses can be employed successfully. It should be understood that while cells 16 having hexagonal sections are illustrated, other configurations may be employed. The term "honey-  
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comb" will be used herein to describe all cell configurations.

The support member 14 is also preferably metallic and may be formed of the same metal as the cellular assembly 12. Support members having a thickness of from  $\frac{1}{8}$ " to  $\frac{3}{8}$ " have been successfully used although it will be understood that other thickness may be employed as required by strength or other purposes, or the support member may be in fact adjacent massive structure.  
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It is contemplated that the above described construction will find particular utility in environments where differences of thermal expansion are to be minimized, where a surrounding casing is radially removed a comparatively great distance from the shaft or other moving part or where a stiff extreme light weight base support is required. If desired, the components may be of materials having different coefficients of thermal expansion, the hottest component being constructed of material having the lower relative expansion thus minimizing warpage.  
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The cellular assembly 12 and the support member 14 may be secured together by welding, brazing or resin bonding.  
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Figure 2 illustrates a modified structure of the unit basically similar to the unit of Figure 1 except that the axes of the cells are angularly related to the plane of the support member. In the manufacture of this type of unit the cellular structure *per se* is developed by corrugating the individual strips at the correct angle prior to assembly. This construction is preferred in certain environments since it increases turbulence of the fluid flowing over the open ends of the individual cells and thus promotes sealing or other flow control. It may also be preferred in certain installations since the cell walls offer less resistance to deformation and thus decrease the possibility of damage between interfering relatively moving parts.  
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Figure 3 illustrates a further modification of the invention which combines the advantages of the units of Figures 1 and 2. In this construction adjacent sides of the cells are joined from the supporting member to the midpoint of the height of the cells so that the upper half of the cells are not attached to adjacent structure and are free to flex in the desired direction. A unit of this type may be manufactured by brazing the cellular structure held together by spot welds at the midpoint of the cell height to the support member with the upper half of the core protected by a braze repellant material.  
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Figures 4 and 5 illustrate a unit of the type shown in Figure 2 installed as a shaft seal, a construction which has proved to be particularly successful. In the installation of Figure 4 a shaft 22 is mounted by means not shown for rotation within a rigid annulus 24. In a typical installation, for example where the shaft 22 supports the turbo-compressor rotor  
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assembly of a jet engine, provision must be made for preventing fluid flow axially of the shaft between it and the surrounding annulus. In accordance with the present invention, the clearance space between the shaft 22 and the annulus 24 may be increased slightly to accommodate an assembly of Figure 2 which, as shown particularly in Figure 4, is arranged in the form of an annulus, the outer periphery of which is defined by the support member 14 secured by any suitable means such as welding or riveting to the inner surface of the annulus 24. In a construction of this type, the honeycomb assembly is preferably made of sheet metal having a thickness of from .001" to .003". The height of the honeycomb cells is preferably selected to provide a radial clearance of from .001" to .010" between the free edges of the cells and the rotating shaft 22. It will be obvious, however, that the clearance may be varied to suit the requirements of the particular installation.

Referring to Figure 4, the seal effected between the unit thereof and the shaft 22 results from the turbulent fluid action in the cells 16 as illustrated diagrammatically by the reference lines 26, after the fluid has passed between the upstream edge of the honeycomb and the shaft. It will be noted that the turbulence of the fluid is augmented by the inclination of the axes of the cells against the direction of fluid flow. A series of such passes, with subsequent energy dissipations which result from the turbulence, throttles the fluid flow and thereby effectively seals the shaft. Both the lateral and vertical dimensions of the individual cells 16 of the honeycomb must be selected to insure the desired turbulence. On the basis of present experience it has been determined that the lateral dimensions of the cells should be a minimum of about .093" and a maximum of about .125". It has been found that a honeycomb having a height substantially equal to the major lateral dimension of a cell 16 produces optimum results. While the unit of Figure 2 is preferred for use as a shaft seal because of the increased turbulence produced by the inclined cells, it has been found that a unit of the type shown in Figure 1 may be used with excellent results.

As suggested above, the units described have a dual function which make them uniquely suitable for installation as shown in Figure 4. In addition to providing an effective shaft seal they also effectively prevent damage between the shaft 22 and the annulus 24 in the event of unbalance, differential expansion or distortion of these parts. If any of these factors occur, the shaft 22 will contact the free edges of the cell structure rather than the backing member 14 or the annulus 24. Because of their light construction the walls of the cells quickly yield and thus accommodate interference by bending and/or wearing. Since the accommodation is accom-

plished immediately and the mass of the honeycomb sections involved is so low, insufficient heat is generated to distort the shaft which would result in further damage. If desirable, anti-gall coatings may be applied to the shaft or the honeycomb or both elements to reduce friction between the parts in the event of interference.

It is to be understood that the invention may be employed with equally good results by the installation of the honeycomb unit on the rotating member as well as on the stationary member as shown. Further it is contemplated that the honeycomb sealing structure illustrated may be used in conjunction with conventional labyrinth rings if desired.

A modified form of shaft seal is illustrated in Figure 6. In this installation the honeycomb assembly is in the form of a ring with a support member 14 extending radially and the axes of the cells extending axially of the shaft 22. The honeycomb assembly coacts with an annular sealing collar 28 with essentially the same action as that described in connection with Figures 4 and 5. If desired the position of the honeycomb assembly and the sealing collar 28 may be reversed, that is, with the honeycomb assembly secured to the shaft 22 and the sealing collar secured to the fixed annulus 24. The seal thus established is equally effective whether the open ends of the cell face the high or low pressure side of the system.

Figures 7 and 8 illustrate a further successful application of the present invention. With more particular reference to these figures, 30 indicates a compressor or turbine blade supported for rotation by conventional means on a rotor hub 32. Surrounding the tips of the blades is a rigid housing or casing 34. In accordance with conventional practice it is necessary in order to maintain the efficiency of the blades that the inner surface of the housing 34 be in close clearance relation with the outer tips of the blades 30. If sufficiently close clearances are maintained to satisfy this requirement there is a substantial risk of interference between the casing and tips of the blades. Since the mass of the parts is relatively high such interference may produce disastrous results. In accordance with the present invention a structural unit of the type shown in Figure 2 is interposed between the casing ring and the tips of the blades with the backing member 14 preferably secured to the inner surface of the casing 34 and the free edges of the honeycomb structure 12 extending radially inwardly into the desired close clearance with the blade tips. Accidental interference between the blades and the edges of the cells is quickly accommodated by bending, wearing or the cutting away of the light thin honeycomb section to permit uninterrupted operation of the engine with little or no damage to the blade. Anti-gall coatings may

be used on the blades or the honeycomb section to reduce the friction in the event of interference.

5 Since accidental interference is not serious, the optimum radial clearance may be used between the tips of the blades and the free edges of the honeycomb and the requirement for excessive clearance to reduce the likelihood of interference between the blade and conventional rub ring is eliminated.

10 It is desirable that the fluid flow between the blade tips and the rub ring be essentially laminar rather than turbulent since turbulence in the blade section decreases efficiency. It has been determined that utilization of small cells in the honeycomb, for example, cells having lateral dimension of .090" maintains the desired flow conditions particularly if the depth of the honeycomb is less than the lateral dimension of the cell.

15 It has been found that the desired flow conditions may be promoted by use of the unit shown in Figure 2 with the axes of the cells inclined in the direction of rotation of the turbine blade as shown. It will be noted that this construction also decreases the resistance to deformation afforded by the honeycomb structure and thus minimizes the risk of substantial damage in the event that interference develops between the honeycomb structure and the turbine blade. However, it has been found that excellent results may also be obtained by substituting a unit of the type shown in Figure 1 for a unit of the type shown in Figure 2 in the environment of Figures 7 and 8.

20 It is to be understood that while, in the examples shown, the present invention has been utilized in connection with relatively rotating parts the invention may be applied with equal success to installations involving relative reciprocatory, oscillatory, transitory and other movements.

25 In any of the foregoing forms of the invention particularly where laminar rather than turbulent flow is desired, it may be advisable to partially or wholly fill the cellular structure with an easily wearable friable, preferably porous material, for example, a cast refractory such as magnesium oxide or plaster of paris to gain superior sealing advantages under certain conditions especially in connection with blade tip sealing. The filler material *per se* need have little strength since it is fully supported by the cellular structure. Certain foam metals may also be used if desired as filler material.

30 From the foregoing it will be apparent that the present invention is effective to prevent damage between relatively moving parts operating in close clearance relation and is effective to maintain desired fluid flow conditions between parts either by establishing the desired flow pattern or interrupting the fluid flow.

65 What we claim is:—

1. Apparatus comprising relatively movable parts and space sealing or filling means interposed between said parts, said means comprising a backing member secured to one of said parts and a cellular assembly rigid with said backing member and extending towards the other part substantially across the space between the parts to form a plurality of cells closed by said backing member and open at their other ends adjacent said other part.

2. Apparatus as claimed in Claim 1 having one of the parts forming a shaft member and the other part forming a surrounding casing member, the backing member rigidly secured to one of said members, and the cellular assembly having a plurality of walls substantially normal to the backing member, said walls being of sufficient height to extend across the space between the members into close clearance relation with the other of said members.

3. Apparatus as claimed in Claim 2, wherein the walls are of thin sheet metal which may be readily deformed by contact with said other member.

4. Apparatus as claimed in Claim 3 wherein said walls extend away from said backing member a distance at least equal to the width of one of the cells of said cellular assembly.

5. Apparatus according to Claim 1 wherein the backing member is in the form of a rigid annulus in spaced concentric relation with the tips of the blades of a bladed rotor, the walls of the cells of the cellular assembly extending substantially radially of said annulus into close clearance relation with the tips of said rotor blades to form a plurality of cells closed at one end by said annulus and open at the other end adjacent the tips of said rotor blades.

6. Apparatus as claimed in Claim 5 wherein the cellular assembly is formed of thin sheet metal readily deformable by contact with said rotor blades.

7. Apparatus as claimed in any preceding claim wherein the cellular assembly has walls formed of sheet metal having a thickness of from .001" to .012".

8. Apparatus as claimed in any preceding claim wherein the cellular assembly has walls which are substantially normal to the plane of the backing member and are arranged to form polyhedral cells.

9. Apparatus as claimed in any one of the preceding Claims 1 to 7, wherein the cellular assembly has walls which are angularly related and other than normal to the plane of the backing member.

10. Apparatus as claimed in any preceding claim having a light weight porous material at least partially filling said cellular assembly.

11. Apparatus as claimed in any preceding claim wherein the cellular assembly has walls which are secured together from the backing member along substantially half their length

whereby the outer ends of said walls are free to flex.

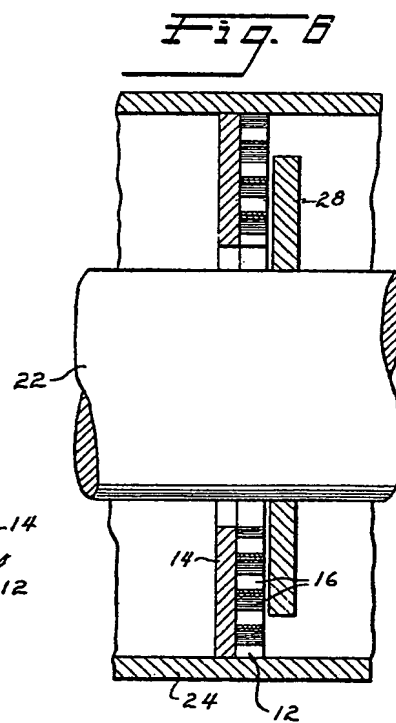
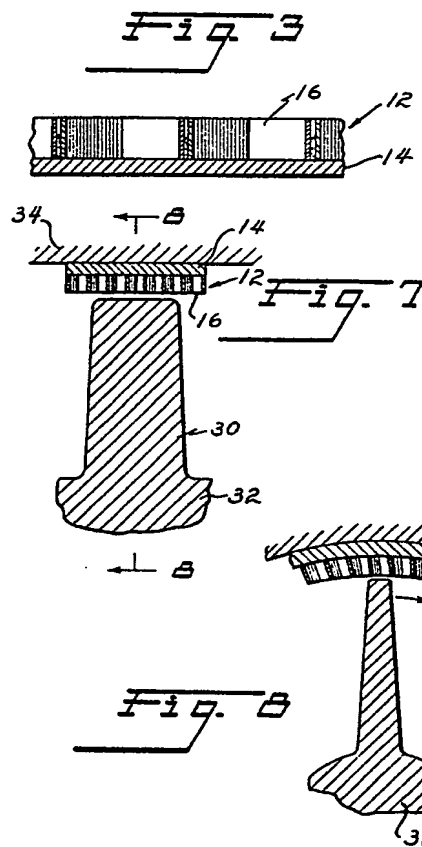
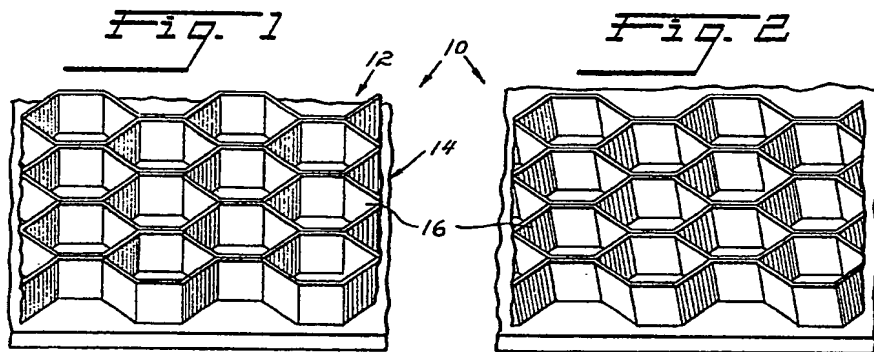
- 5 12. Apparatus as claimed in Claim 1, wherein one of the parts is in the form of a shaft and the other part is in the form of a surrounding casing, and the backing member forms one of a pair of annular members having radially extending opposed spaced faces, one of the annular members being secured to said shaft  
10 and the other of said members being secured to said casing, the cellular assembly being

rigid with the backing member forming one of said pair of annular members and extending across the space into close clearance relation with the other annular member.

- 15 13. Apparatus comprising relatively movable parts and space sealing or filling means interposed between such parts, such as described with reference to Figures 1 to 4, Figure 6 or  
20 Figures 7 and 8 of the accompanying drawings.

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2 SHEETS

This drawing is a reproduction of  
the Original on a reduced scale.

SHEETS 1 & 2

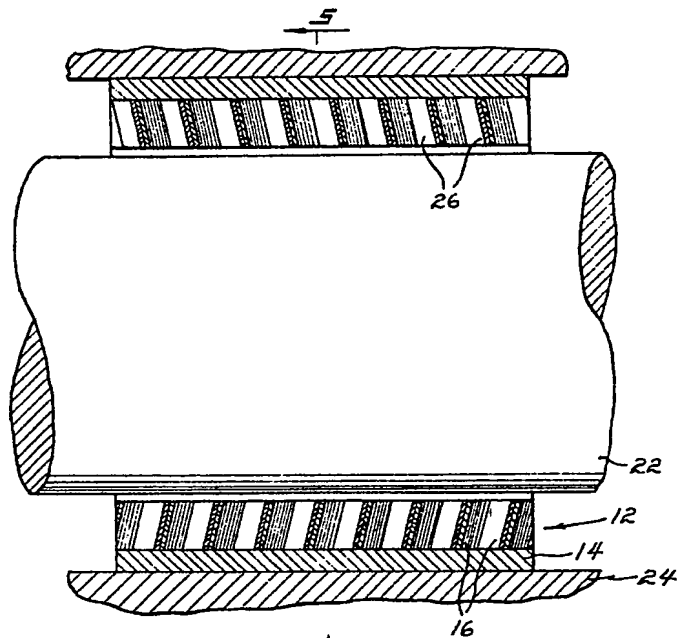


Fig. 4

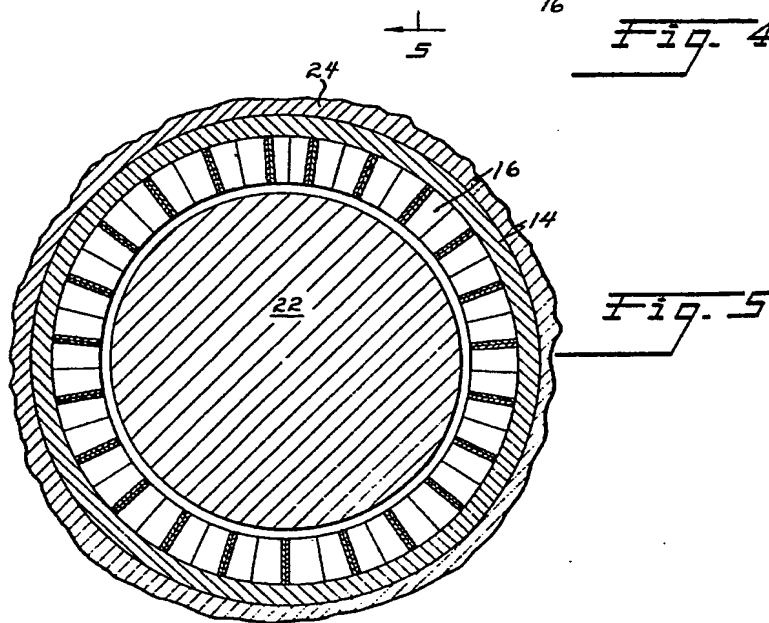


Fig. 5

